Sept. 25, 1956 D. H. LEE 2,764,514

PROCESS FOR PRODUCING STEEL RODS FOR PRESTRESSING CONCRETE

Filed June 28, 1954 2 Sheets-Sheet 1

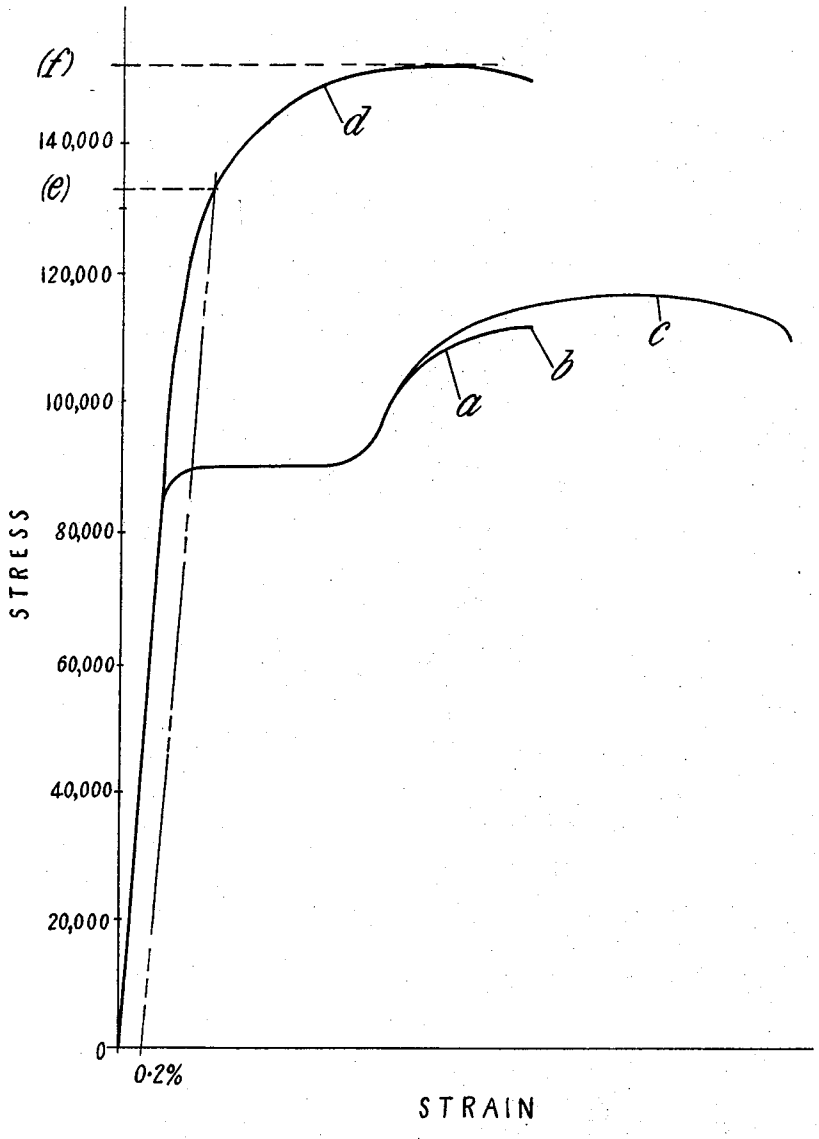


Fig. 1.

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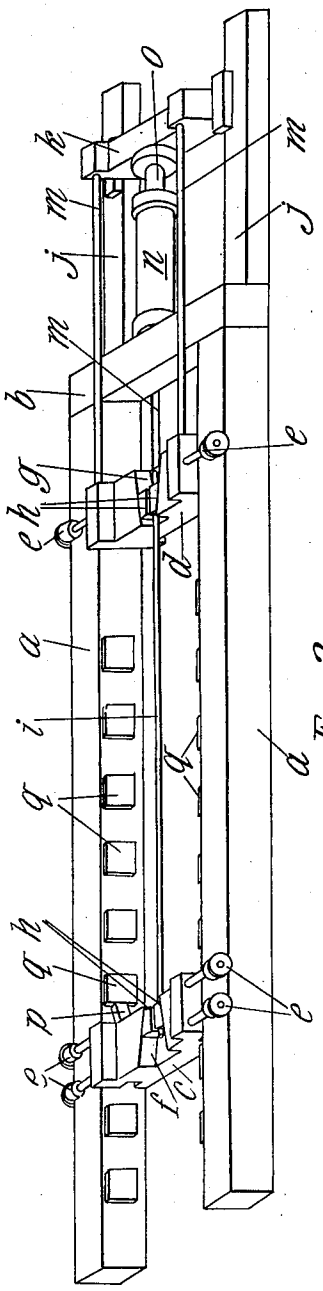


Fig. 2.

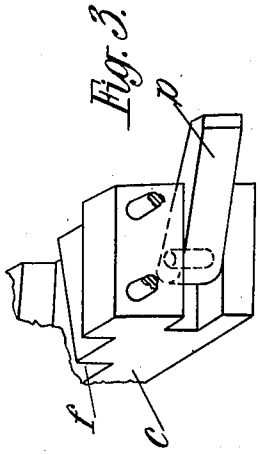


Fig. 3.

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PROCESS FOR PRODUCING STEEL RODS FOR PRESTRESSING CONCRETE

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Application June 28, 1954, Serial No. 439,805

Claims priority, application Great Britain October 17, 1949

7 Claims. (Cl. 148—12.3)

This invention relates to high tensile high carbon steel bar, rod or wire more particularly for use in the prestressing of structural materials, such as concrete, cast iron and mild steel, and has for its object the provision of an improvement in the production of such bar, rod or wire by which the steel is given desired physical properties. This application is a continuation-in-part of my earlier application, Serial No. 405,427, filed January 21, 1954, now abandoned, which in turn is a continuation-in-part of my application, Serial No. 181,863, filed August 28, 1950, now abandoned.

It will be appreciated that the bar, rod or wire hereof differs only in degree of thickness, if at all, and to avoid use of alternative expressions the term "bar" is used in the claims as generic to such shapes.

It is known to stretch mild steel (carbon content up to say, 0.3%) for the purpose of raising the yield point and reducing the ductility as measured by the elongation, and it is also known to stretch and twist similar mild steels in various ways, for example stretching and twisting steel bars so that the outer surface receives more cold working than the interior due to the applied torsion. Such treatment can only be employed satisfactorily with mild steels which are not suitable for efficient use in the prestressing of concrete, where a very high ultimate strength is essential. For prestressed concrete work, high carbon steels (carbon content of 0.5% and over) can only be utilized, more particularly high carbon steel alloys of particularly high ultimate strength properties.

Such high carbon steels or steel alloys initially have a lower ductility than mild steels, and therefore to subject them to any combination of stretching and twisting (as used in the case of mild steels) is not practical owing to their liability to structural damage or deterioration as a result of the cold work produced on the external surface by twisting added to that produced by stretching; this may, for example, be partly due to the surface of such high carbon steels being air hardened. With the limited amounts of cold work that are therefore possible with these high carbon steels, simple stretching which imparts a uniform amount of cold work to the steel throughout its whole section leads to less risk of brittle fracture at this stage. Furthermore, for prestressed concrete work it is very desirable that all bars should be tested before being used and cold working by controlled simple stretching has the additional important advantage that any physical defect in the bar is immediately disclosed although perhaps not visible.

There are, however some high carbon steels in which the yield point cannot be raised by cold stretching, as immediately the yield point is exceeded in one part of the bar, fracture follows. It is therefore necessary to use only a steel in which the yield point of the hot rolled bar before stretching is distinct and definite, so that during the actual stretching operation immediately one part of the bar reaches the yield point the cold working in that part immediately raises the yield stress there, and the cold work thus spreads progressively to all parts of

the bar. To achieve this, it is necessary initially to apply the stretching force so that the yield point of the as-rolled bar is reached gradually, and thereafter is exceeded to between 70% and 90% of the ultimate strength of the bar. As an example, a high carbon alloy steel, having a composition of carbon between 0.5% and 0.65%, silicon between 1.5% and 2.2% and manganese up to about 1.5% is particularly suitable for such treatment since in the as-rolled condition there is a pronounced yield point around 40–45 tons per sq. in.

As a further example a high carbon steel having a combined chromium and silicon content of up to about 2.5% can also be used if great care is taken to observe the treatment requirements described hereafter. Such a steel may have a composition falling within the ranges of carbon from 0.35 to 0.65%, manganese up to 1.5% and a combined chromium and silicon content up to 2.5%, of which the silicon content is up to 0.5%. Steel of either of these compositions after rolling to form the rod can have an ultimate strength of about 70 tons per square inch and a yield strength about 0.6 of its ultimate strength. By stretching according to the invention, such a rolled steel bar about 3 to 5% of its original length, the stress-strain curve for the steel after stretching will show an increase in the length of the straight part of the curve such that there is practically no curvature between zero stress and a stress corresponding to 0.7 or more of the ultimate strength of the steel. This form of stress-strain curve of the steel after stretching indicates physical properties of the steel which are particularly suitable for prestressed concrete where ductility is not particularly advantageous, but absence of creep of the steel at high stresses is important.

As an example it is desirable that there shall be no creep at constant length at a working stress which may be of the order of 60% to 70% of the ultimate strength of the steel and by the method now described this result is obtainable.

It is to be appreciated that the percentage stretch of 3 to 5% as given above is a suitable percentage stretch for the type of steel referred to above, and that with other types of steel the most suitable percentage stretch of the bar may be higher or lower.

While it is usual for prestressed concrete work to use wire in which the elongation at breakage is very small, say of the order of 4%, bars of the diameters of the order of 1" have greater stiffness and are consequently more liable to being overstressed in transport or handling. For this reason greater ductility of the steel is desirable and is obtainable by the process now described. By this means bars subjected to stresses, during transport and handling, after the processing described, which exceed that of the straight part of the stress strain curve, receive more cold work instead of being liable to incipient fracture as can very readily occur with steel having the physical properties of wire as at present used. Moreover, for prestressed concrete work it is desirable, and is one of the purposes of this invention to provide, a steel in which the final physical properties are as closely uniform as possible, notwithstanding the fact that, with all skill shown in the making of the steel it is not a practical possibility to maintain uniformity of the desired selected chemical composition.

The stretching of the rod provides a form of cold working of the steel which increases the yield stress such that the marked yield point, on the stress-strain curve appropriate to the steel before stretching, disappears and the stress-strain curve after stretching shows a practically straight portion to a much higher stress.

According to the invention, for the prestressing of structural materials such as concrete, cast iron or mild steel, high carbon steel bar of the type indicated is sub-

jected to controlled single linear stretching to raise the proof stress and reduce the ductility. By "simple" stretching is meant stretching with the avoidance of any twisting or applied torsional distortion.

The invention also consists in preconditioning hot rolled high carbon steel rod for the prestressing of structural materials such as concrete, cast iron or mild steel, by subjecting the rod to a controlled cold simple linear stretching until the yield point is determined to have been raised to over 70% of the ultimate strength and the ductility as measured by elongation on unit length (e. g., an 8 inch gauge length) is not less than 6% nor more than 15%, such that creep at constant length is thereby rendered negligible at 60% (about 80,000 p. s. i.) of said ultimate strength.

Further, in accordance with this invention, high carbon steels of the type described are subjected to a simple linear stretching to a residual elongation which, after the elastic recovery has occurred, is substantially inverse to the equivalent carbon content. By equivalent carbon content is meant the percentage of carbon plus the proportion of the silicon, manganese, chromium or other elements present, expressed as a percentage of carbon in known manner as effective in raising the ultimate strength in the as-rolled condition. The use of the equivalent carbon content has been found, in practice, to be a convenient method of determining the stretch to be given to any particular steel, to obtain the optimum properties of proof stress and ductility, but the variation of the percentage stretch inversely to the equivalent carbon content is part of this invention whereby steels of slightly varying chemical analysis after stretching have a practically uniform 0.2% proof stress, and therefore in a given construction all bars have essentially the same physical properties and give virtually identical performances.

Further, since stretching of high tensile steels of the high carbon type described cannot ordinarily be carried out except under very favourable conditions of temperature and ageing, further precautions are required. For example, in the cooling of billets prior to the rolling into bars, hydrogen may become occluded, in which event brittle fracture may follow immediately on subjecting bars to cold working. Therefore, billets of high carbon steel are preferably subject to treatment to reduce the occurrence of occluded hydrogen, for example, controlled cooling to allow any occluded hydrogen to escape.

However, even with such precautions, steels with 0.5% carbon or more may still have occluded hydrogen in the bar after rolling from the billet and retain a consequent marked susceptibility to brittle fracture during the cold stretching. For example under low temperature conditions steels of this high carbon type, even those in which the phosphorus content is quite low, are sensitive to cold working. Therefore supplementary to the procedure described above, in cold weather or at other times when found desirable, the bars are subjected before stretching to a heat treatment in water for a period up to 48 hours to give them an artificial ageing. Stretching may be effected while the bars are still warm from this treatment.

Since the propagation of any minute crack in the surface of the steel is closely related to the notch sensitivity, and the latter is increased the lower the temperature of the steel when being stretched, it is very desirable to warm bars in cold weather to not less than about 50° F. This is also desirable although it may be known no minute surface cracking exists since minute slag or other inclusions or surface irregularities may have the same effect of being stress raisers.

Further as cold working becomes increasingly ineffective the higher the steel temperature at the time, it is desirable to limit the maximum temperature so that it does not exceed the lower inter-crystalline transition

temperature. The latter varies with the chemical composition of the steel and also with any impurities but is generally below 300° F. Assuming no impurities present a stretching temperature range of 50° F. to 200° F. is generally satisfactory.

In what follows there is described with the aid of drawings stress strain curves and particular examples of steel treated and stretched according to the invention, and apparatus for carrying out the stretching.

In the accompanying drawings:

Figure 1 is a diagram showing stress strain curves produced at various stages of treatment and stretching of a particular steel according to the invention,

Figure 2 is a diagrammatic view in perspective of one form of apparatus suitable for stretching and testing steel rod or wire according to the invention, whilst

Figure 3 is a detailed view of part of one of the clamps used in the apparatus of Figure 1.

Referring to Figure 1, curve *a* shows the typical properties of a steel in its as-rolled condition, which has carbon and other optional elements in sufficient proportion to give an ultimate tensile strength of 140,000 p. s. i. or over.

The brittleness of this steel immediately after rolling, shown by curve *a*, is particularly characterised by a small elongation up to the point *b* of fracture, which will vary with known factors such as chemical composition and with lesser known factors, which this invention is more particularly concerned, including rolling strain, and occluded hydrogen.

After the pre-treatment disclosed in this specification and prior to stretching, the stress-strain curve *c* for the steel shows increased elongation. Without such pre-treatment the stretching of steel of this tensile strength is impossible without sudden fracture or except as the result of fortuitous circumstances not deliberately repeatable.

After the pre-treatment and the stretching according to the invention the stress-strain relationship is typically represented by curve *d*.

It will be appreciated that the percentage of stretch can be varied so that the desired ratio of proof stress *e* to ultimate strength *f* is obtained and for the prestressing of concrete this is between 0.7 and 0.9 in the case of a 0.2% proof stress, over 120,000 p. s. i.

The following examples are given in order to make more clear the procedure, according to the invention, necessary to obtain steel bars with the desired physical properties.

In the examples the bars are assumed to be of steel having a carbon content sufficient to give an ultimate strength of 140,000 p. s. i. or over, or alternatively carbon with other elements which together have the same result.

In Example 1 the steel has no alloying elements which reduce ductility and it is also fully killed. The billets or bars of such a steel are first subjected to controlled cooling to remove rolling strain and occluded hydrogen. The stretchings of the bars may then be carried out if the ambient temperature is 60° F. or over; if not immersion in heated water for 1 hour is normally sufficient.

In Example 2 the bars are of a steel of 140,000 p. s. i. ultimate strength, an alloy containing silicon and manganese as described earlier. It is assumed that controlled cooling of billets or bars cannot or has not been carried out. The bars are first aged by storage in air at a temperature and time depending on the expected, or determined, hydrogen content of the steel. On the average this will be 4 weeks at 60° F. after which they can be stretched in accordance with the invention as described earlier.

In Example 3 the steel bars are of any alloy composition but having a carbon content over 0.50% and giving 140,000 p. s. i. ultimate strength or over. To enable stretching of these bars in any climatic condition without previous controlled cooling or ageing in air for sev-

eral weeks, the bars are immersed in hot water for a period of 4 to 20 hours at 200° F. down to 100° F., the time and temperature being approximately interchangeable and greater time or temperature being provided where occluded hydrogen is believed, or known to be greater than normal.

Such treated bars are then stretched while still warm, that is at a temperature between 60° F. and 200° F.; the lower temperature being sufficient for safe stretching being above the critical limit of 50° F. mentioned above.

It will be appreciated from the foregoing that, notwithstanding the practice in the steel industry to carry out cold working by stretching and twisting in various ways to give a raised yield point to the steel and sometimes to raise the ultimate strength of high carbon steels for the purpose of prestressed concrete work, those methods are inadequate. Several years of experiment and research were needed to discover a procedure that would enable high strength high carbon steel bars to be made specifically suitable for prestressed concrete work to eliminate brittle fractures during processing and also, incidentally, to ensure the testing of every bar against the possibility of invisible or non-apparent defects which might lead to incipient fracture when the bar was subsequently tensioned in use.

In order to effect the stretching of the steel bar in accordance with the invention the bar either in a single length or a number of lengths together, may be clamped at its or their ends and a force applied to one or both clamps by means, such as for example hydrallic cylinder and ram means, which may be controlled to give the rod or wire the predetermined extension at which the steel obtains the desired physical properties.

A convenient apparatus for carrying out the controlled simple linear stretching of high carbon steel rod is shown in Figures 2 and 3, in which the apparatus comprises two side or strut members *a* which are joined together at one end by an end member *b*. Located between the side members are two clamps *c* and *d* which are capable of movement between and longitudinally of the side members *a*. Rollers *e* carried by the clamps ride upon the upper surface of the side members in order to support the clamps and facilitate their movement upon the side members.

The clamps *c* and *d* are provided with opposed tapered slots *f* and *g*, and in each slot there is a pair of wedge-like dogs *h* which have serrated inner surfaces for gripping the ends of the steel rod *i* to be stretched between the clamps.

Arranged for sliding movement upon and between extensions *j* of the side members *a* is a cross head *k* which is connected to the clamp *d* by four draw bars indicated at *m*. As shown the force for stretching the rod *i* is supplied by hydraulic cylinder and ram means of which the cylinder *n* is secured to the end member *b* and the ram *o* acts upon the crosshead *k*.

The position of the clamp *c* between the side members *a* is made adjustable in order to provide for variations in length of the steel rods *i* to be stretched, and for this purpose the clamp *c* is provided at its ends with hinged sprags or pawls *p* (see Figure 2) which engage tooth or rack formations *q* on the insides of the side members *a*.

With the arrangement above described the force applied by the ram *o* to the crosshead *k* is transmitted by means of the draw bars *m* to the clamp *d*. Simultaneously the reaction of the thrust of the ram upon the crosshead is taken by the end member *b* and spread thereby on to the two side members *a* which in turn transmit

it to the clamp *c* by means of the sprags *p*. Thus the rod *i* is stretched by a force applied at each end of the rod by the clamps *c* and *d*.

Suitable pointer and scale mechanism, for example upon the clamps and side members respectively, may be provided for measurement of the stretch of the rod *i*, and in addition suitable pressure measuring means may be provided for measuring the pressure in the hydraulic cylinder or the supply main leading to it. With the aid of the readings from these measuring means a careful control of the strteching of the steel bar can be obtained.

The invention is primarily suitable for the production and coincident testing of steel bars for use in prestressed concrete, but it may also be used for the production and coincident testing of steel bars to be used for other purposes, such as tie bars suitable as wind bracing for the frameworks of buildings and bridges and also as the tie bars of sheet piled walls for docks and river walls.

I claim:

1. A method of producing a high tensile steel member for prestressing concrete and other structures which comprises providing a rolled bar containing 0.35% to 0.65% carbon, manganese up to 1.5% and silicon up to 2.2%, said bar having an ultimate strength exceeding 140,000 p. s. i., a 0.2% proof stress of over 120,000 p. s. i. and substantially no creep at a stress of about 60% of the ultimate strength, said bar being non-stretchable in the as-rolled condition, the steps comprising aging said bar to remove occluded hydrogen and then stretching the bar by slowly applying tension to the bar so as to approach and exceed the yield point, whereby a yield point flow spreads along the entire length of the bar when the yield point is reached, the application of tension being continued until the bar has been given a permanent elongation of from 3% to 5% and said proof stress is obtained.

2. The method as defined in claim 1 wherein the bar is aged to remove occluded hydrogen by soaking in water at a temperature exceeding 100° F.

3. The method as defined in claim 1 wherein the bar is aged to remove occluded hydrogen by maintaining it for a period after rolling of at least one week in air at a temperature exceeding 50° F.

4. The method as defined in claim 1 wherein the aging step comprises slowly cooling a hot bar from a temperature substantially higher down to about 300° F. and then stretching said bar.

5. The method as defined in claim 1 wherein the composition of the metal stretched comprises carbon from 0.35% to 0.65%, manganese up to 1.5% and a combined chromium and silicon content up to 2.5% of which the silicon content does not exceed 0.5%.

6. The method as defined in claim 1 in which the metal composition has carbon in the range of 0.5% to 0.65%, silicon 1.5% to 2.2% and manganese up to 1.5%.

7. The method as defined in claim 1 in which the aged bar is heated to the range of 50° to 300° F. and then stretched.

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